



Macro-, meso-, and micro-scale genetic population structure in Pacific cod: applications for fisheries management and conservation

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Outline

- The fish, fishery and management
- Population Genetics 101 and the special case of high-latitude marine species
- Macro-scale structure
- Meso-scale structure
- Micro-scale structure

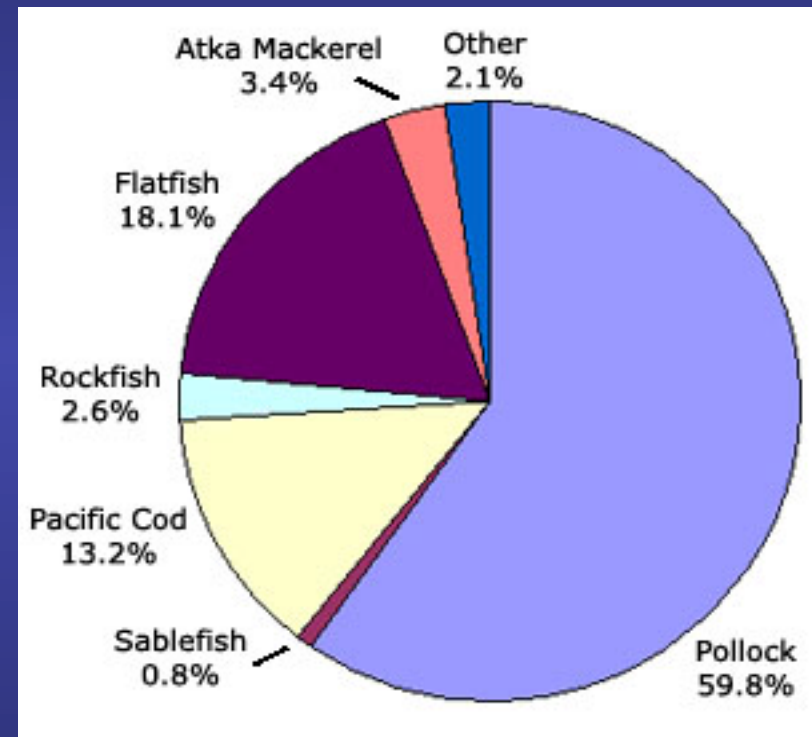
Gadus macrocephalus



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Pacific cod (*Gadus macrocephalus*)

- Second largest groundfish fishery in AK ~ 99% of cod landings in US
- Eclipsed Atlantic cod landings in mid 1980s
- 2008 landings 229K mt ~ \$425 million
- ~ 18% of value



2008 catch

Pacific cod (*Gadus macrocephalus*)

Life history characteristics

- Transoceanic
- Temperate/subpolar
- Demersal shelf/slope
- Lifespan ~ 18 y
- Age @ 50% maturity ~ 5y
- Highly fecund, demersal eggs, fast growing
- Seasonal migration

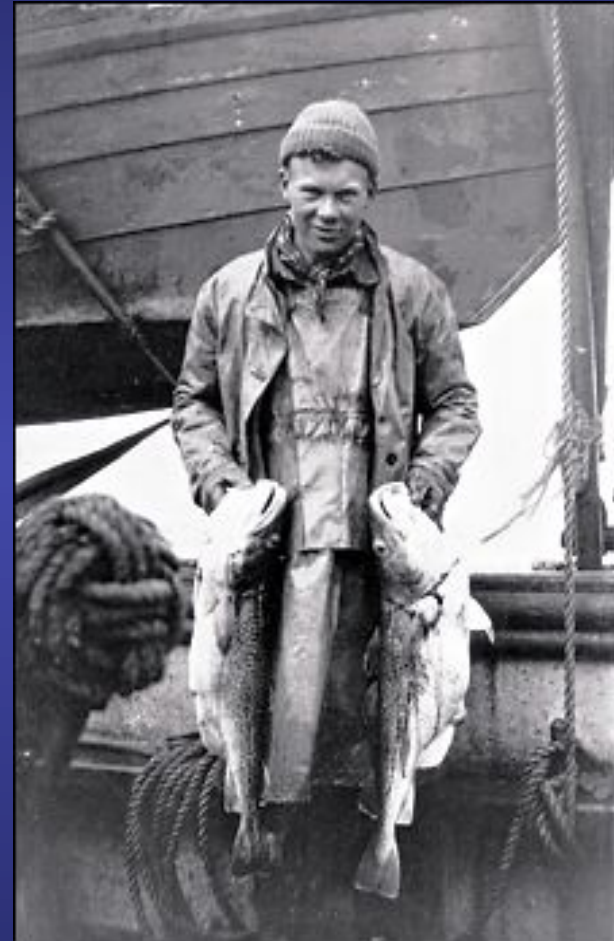
'Ecological' stocks worldwide

- 2 – 12, no consensus

'Evolutionary' stocks worldwide

Grant et al. 1987 – allozymes

- Two stocks - NA and Asia

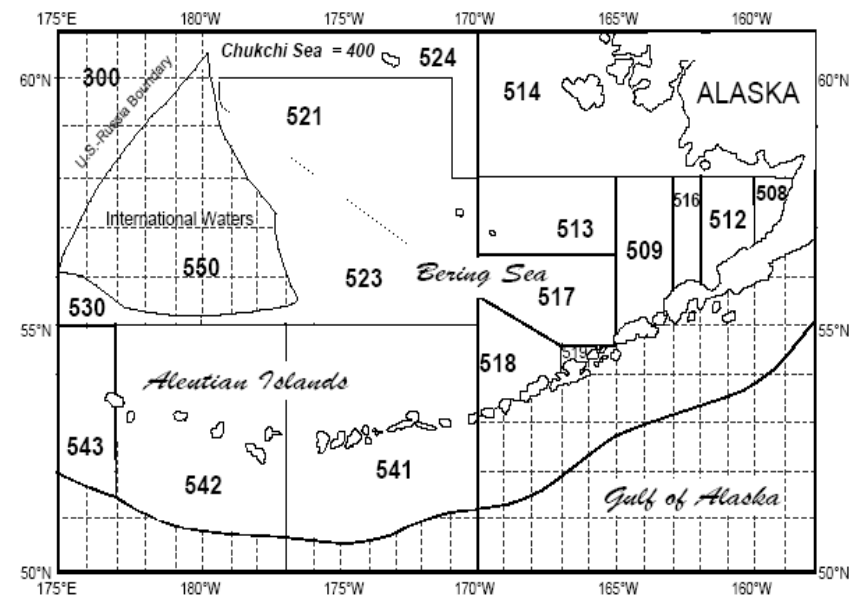
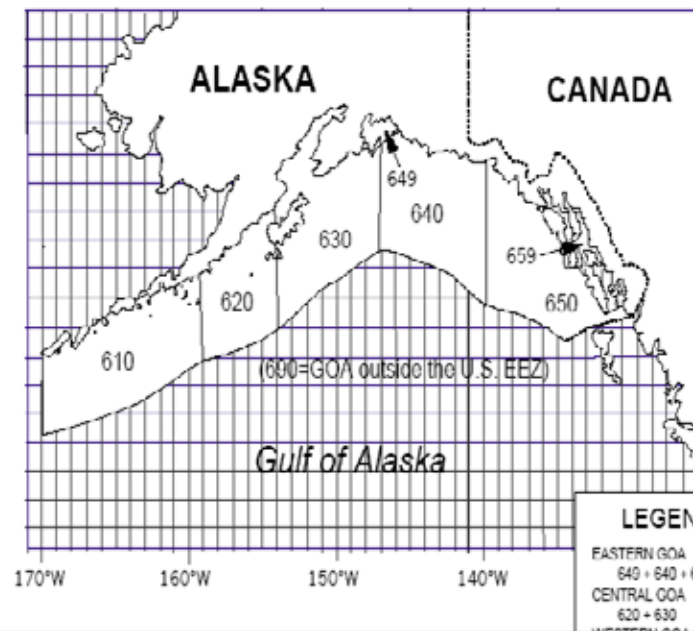


source:<http://seattletimes.nwsources.com/art/pacificnw/2004/0502/taste01.jpg>

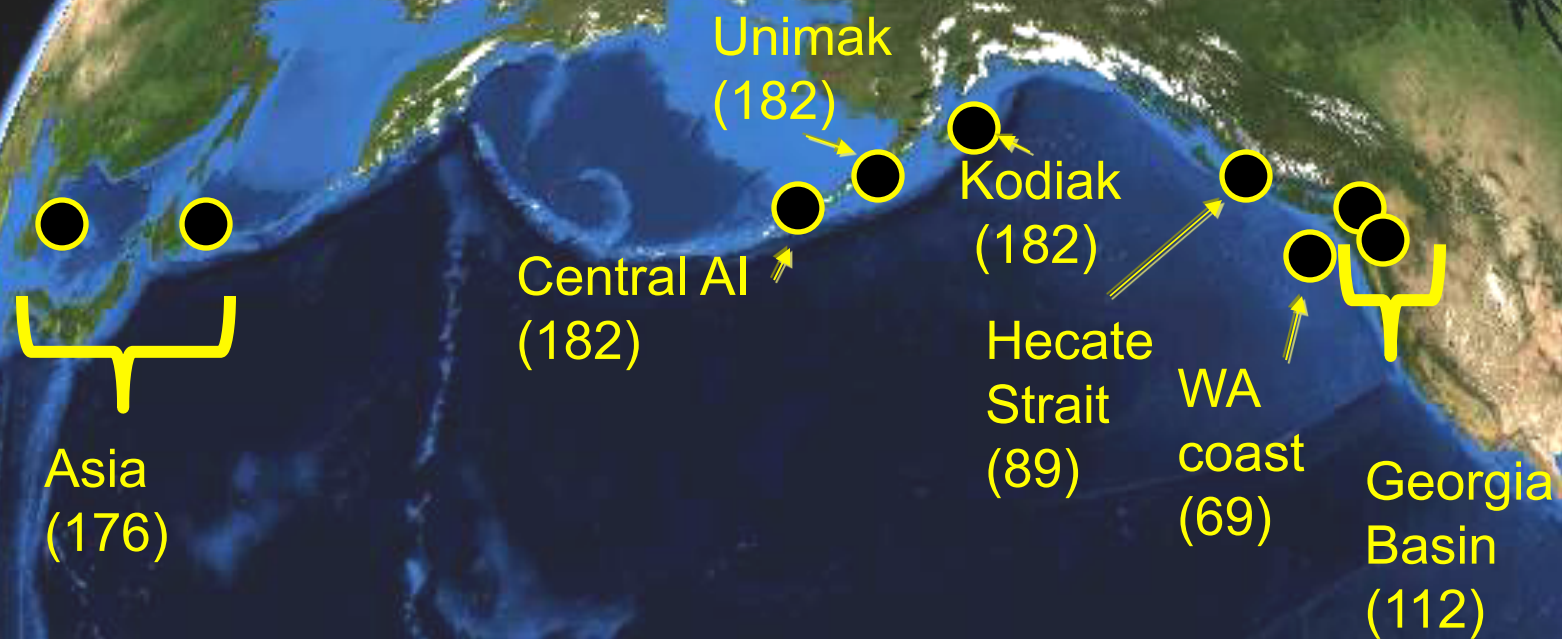
Two management units in Alaska

Gulf of Alaska
(GOA)

Bering Sea/Aleutian
Islands (BSAI)



Pacific cod msats

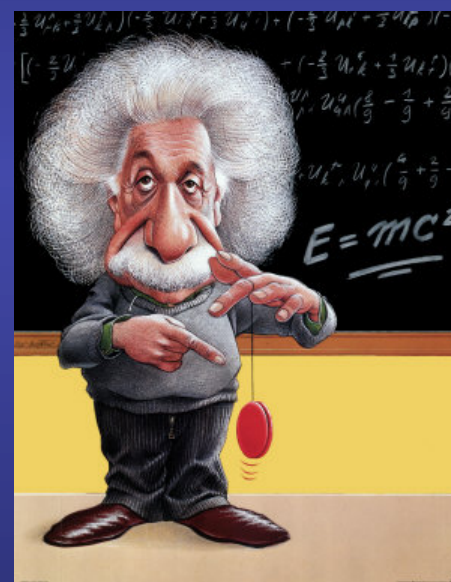


11 microsatellite loci

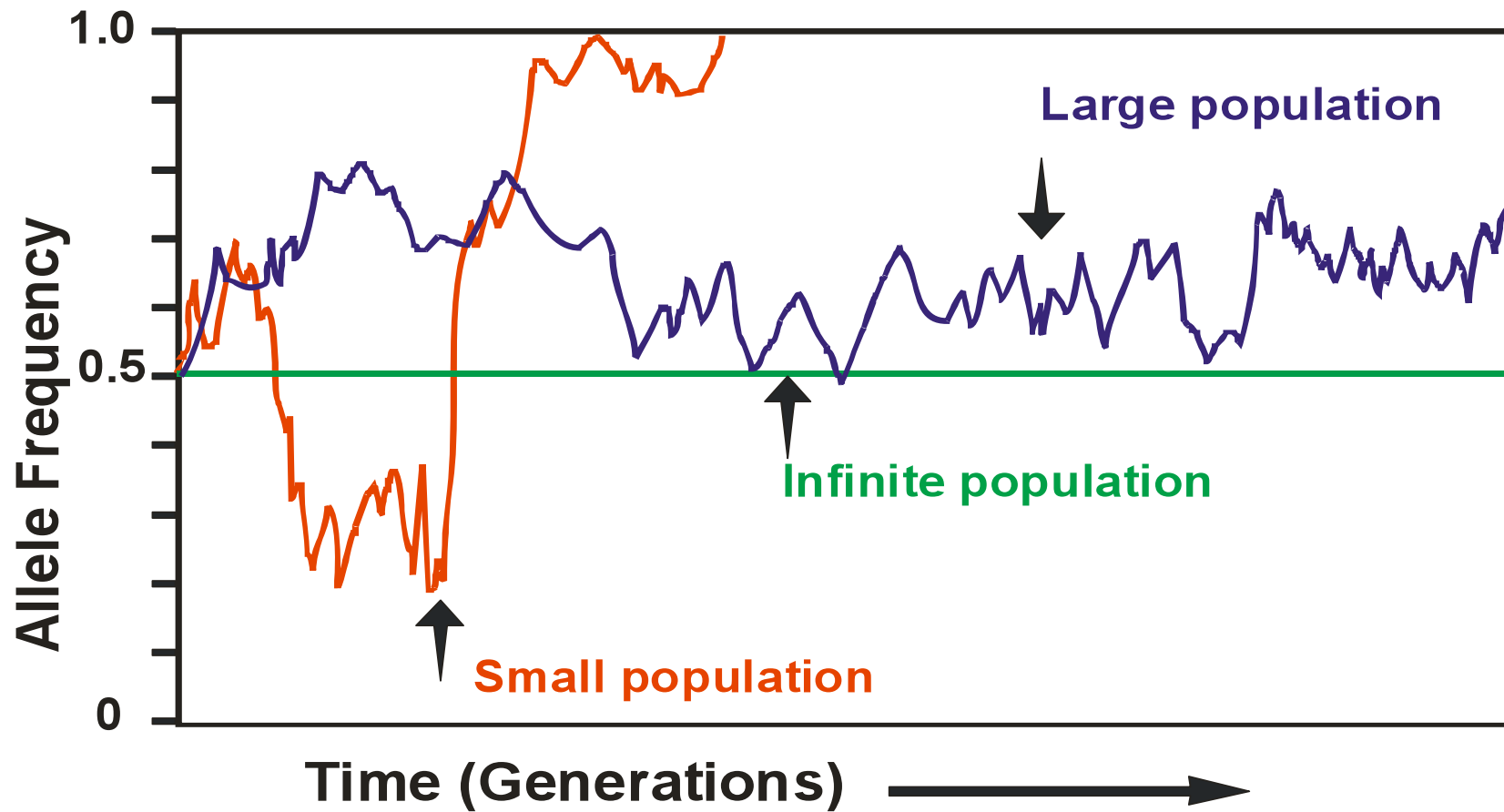
Evolutionary forces that cause genetic differentiation

- Mutation - creates
- Migration - moves
- Genetic drift - diverges
- ~~Natural selection~~

First a bit of theory

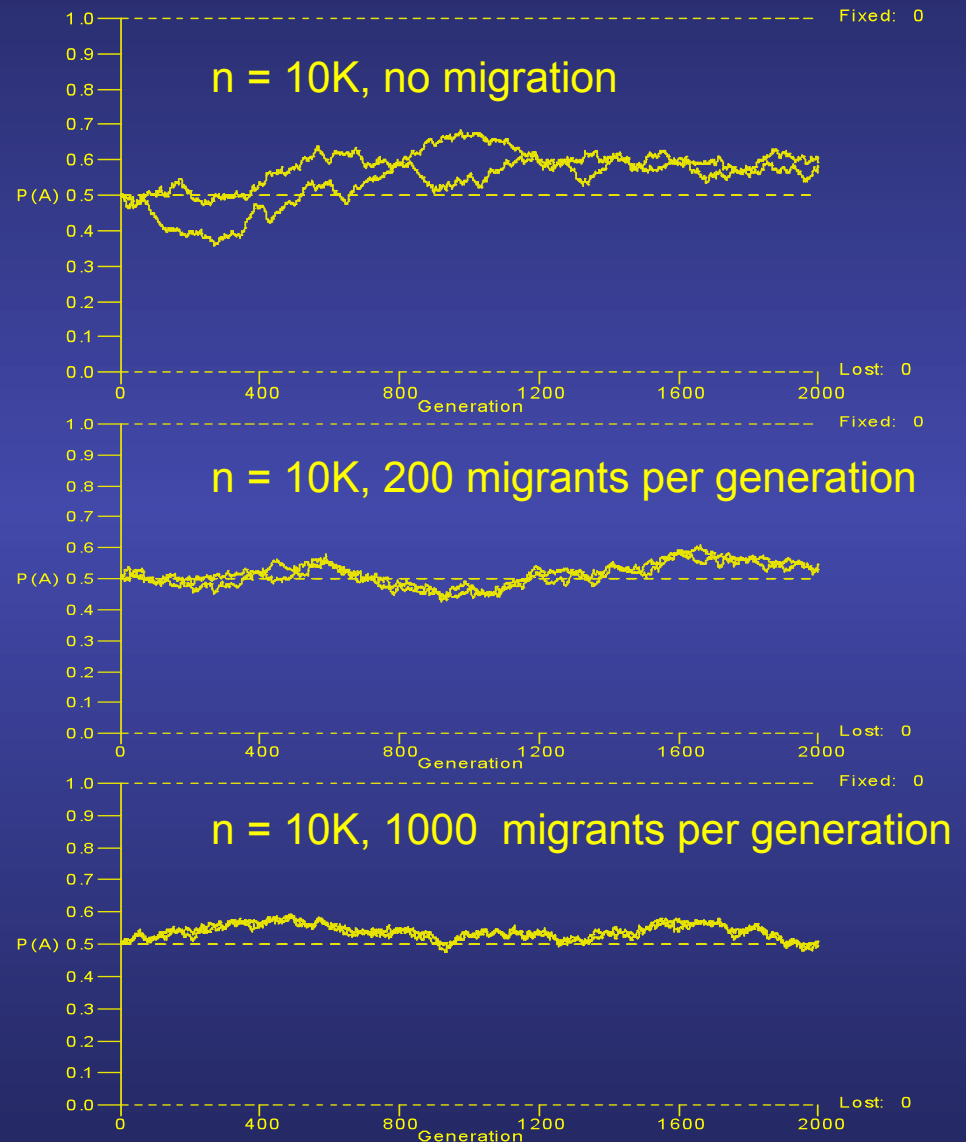


Genetic drift

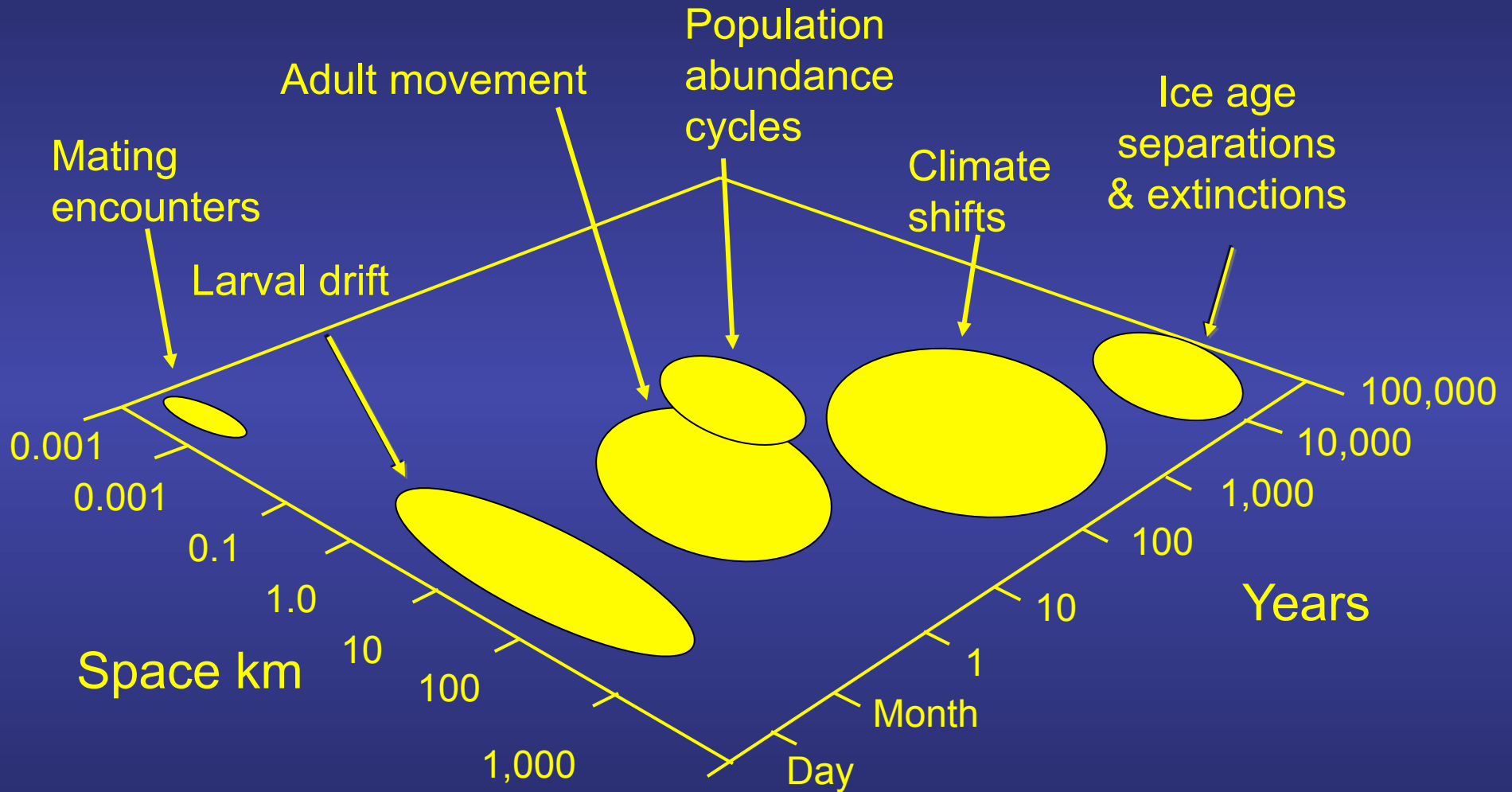


Genetic drift and migration

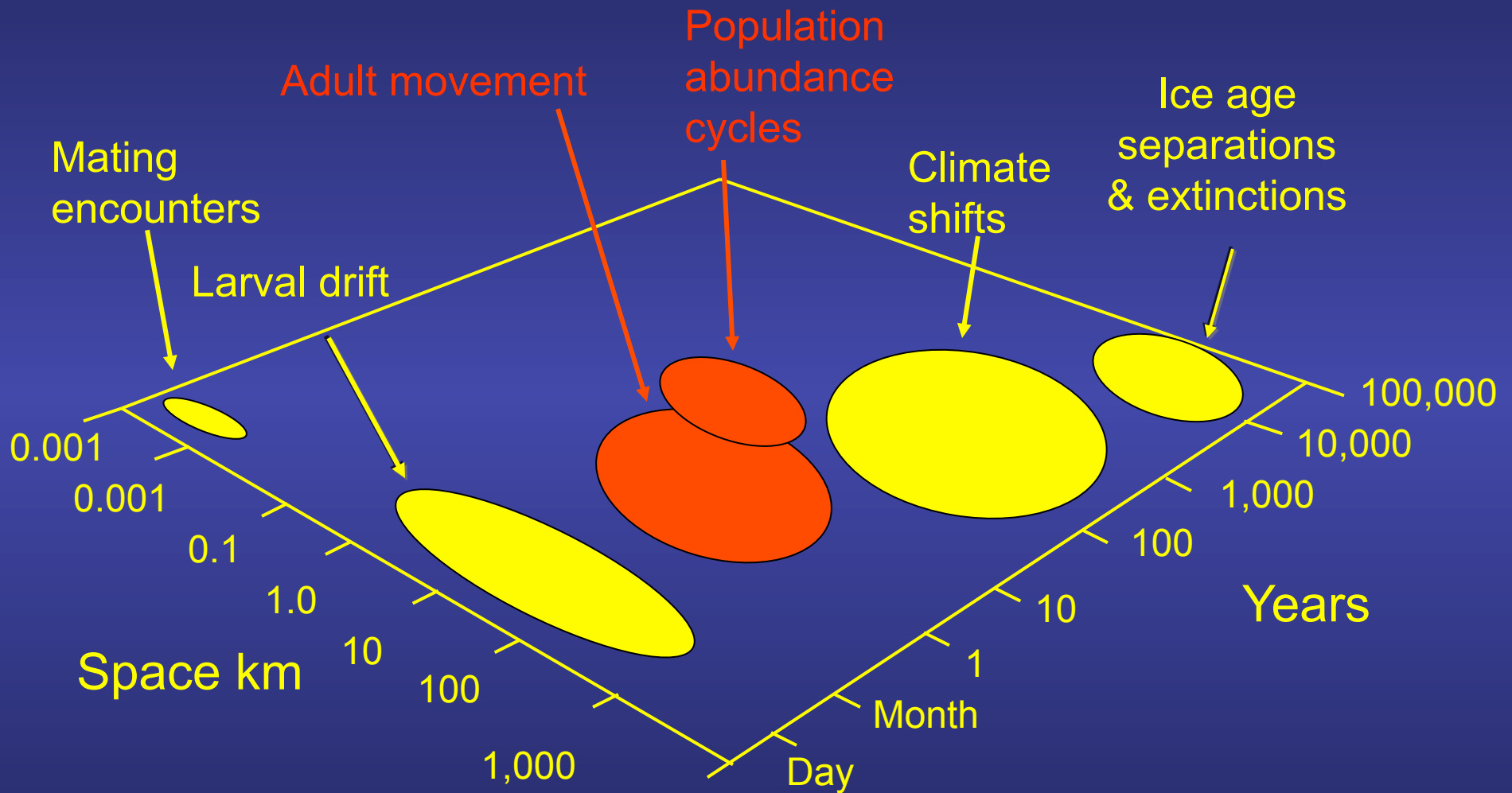
- opposing forces
- weak effect of drift easily overwhelmed by trivial amounts of migration (e.g. when $N_e m > 1$)
- ‘evolutionary’ stock criterion most stringent
- less power to detect ‘ecological’ stocks



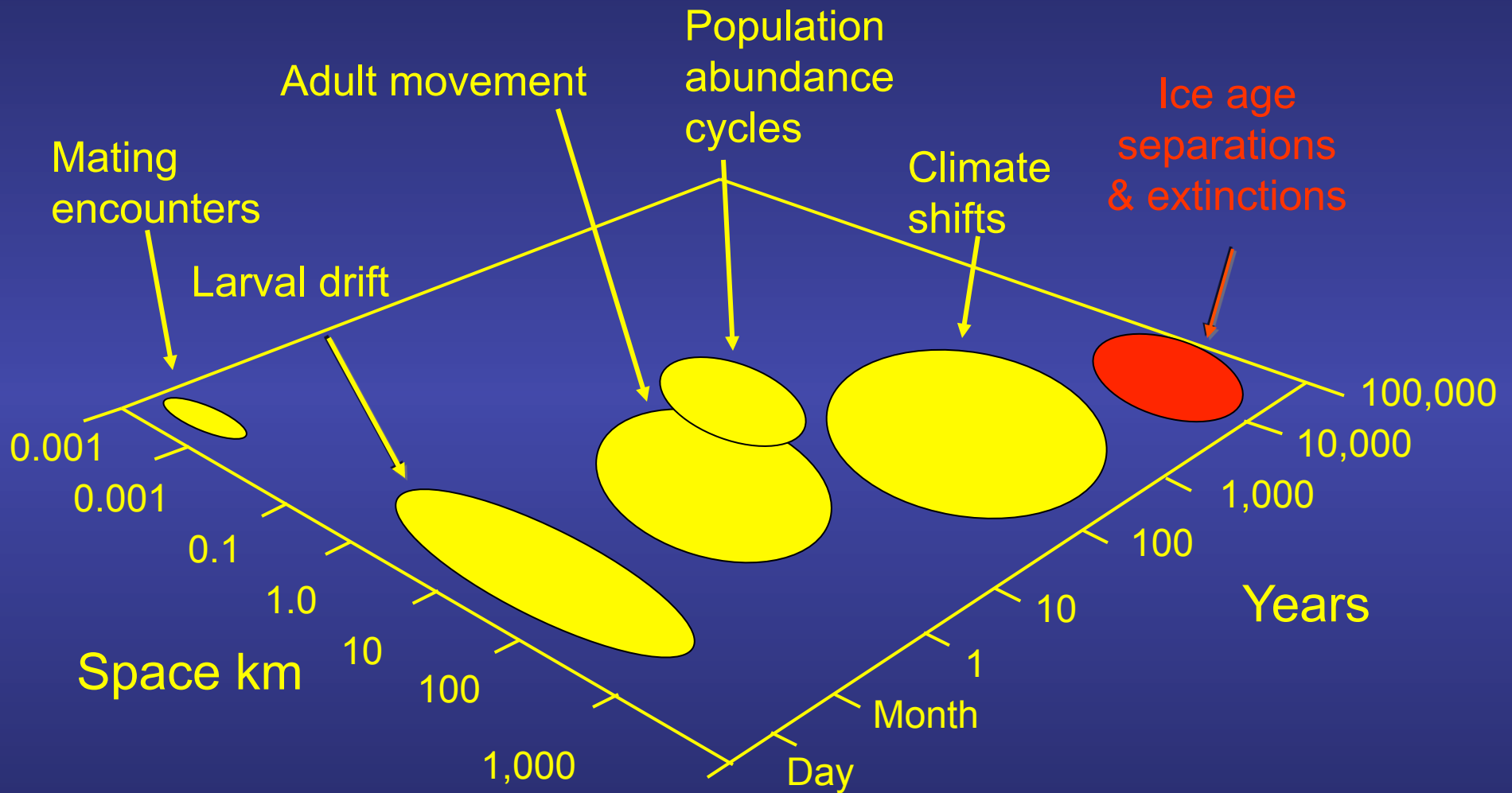
Sources of Genetic Population Structure



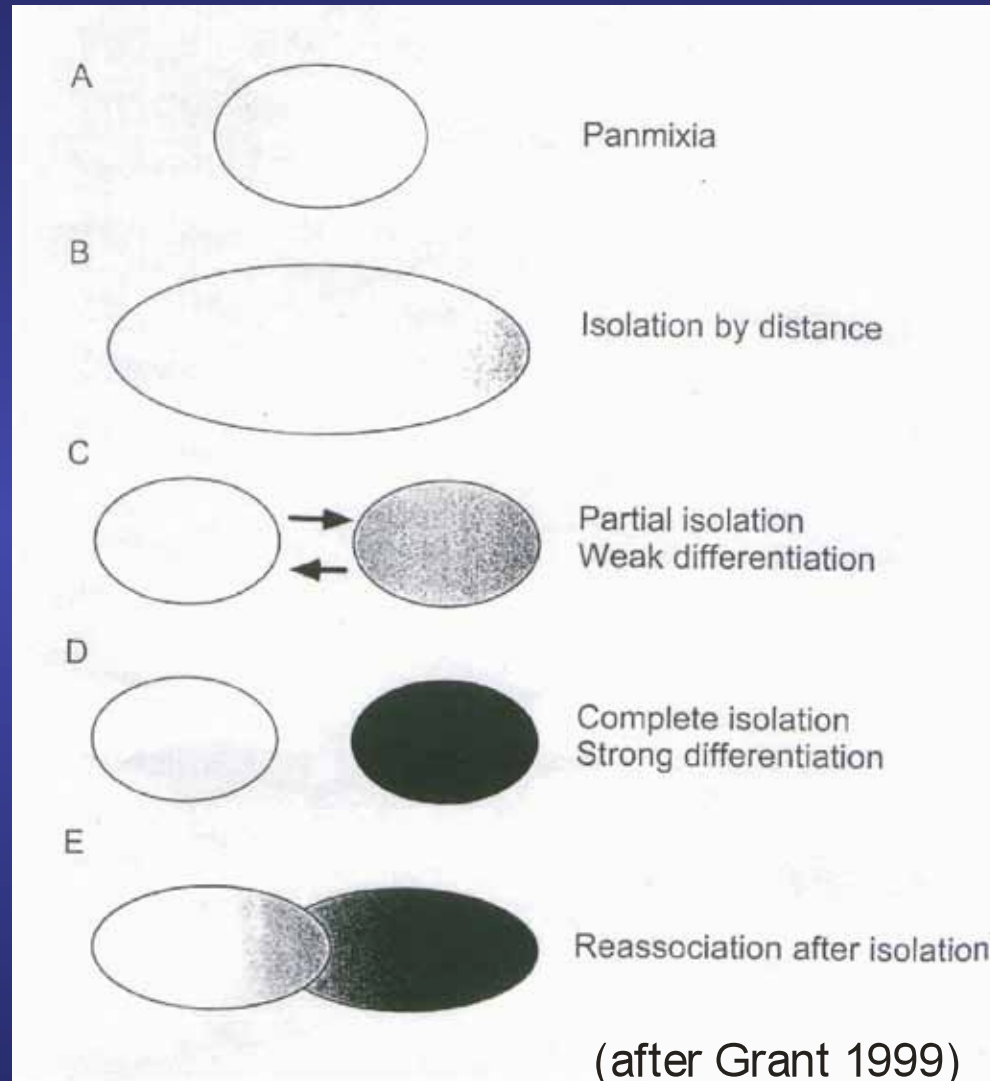
Sources of Genetic Population Structure



Sources of Genetic Population Structure



Patterns of neutral differentiation



The special case of high-latitude marine fishes

- Huge population sizes – drift negligible
- High potential for dispersal (e.g. egg/larval drift, migration)
- Cyclical extinctions/recolonizations during ice ages

The times they've lived through

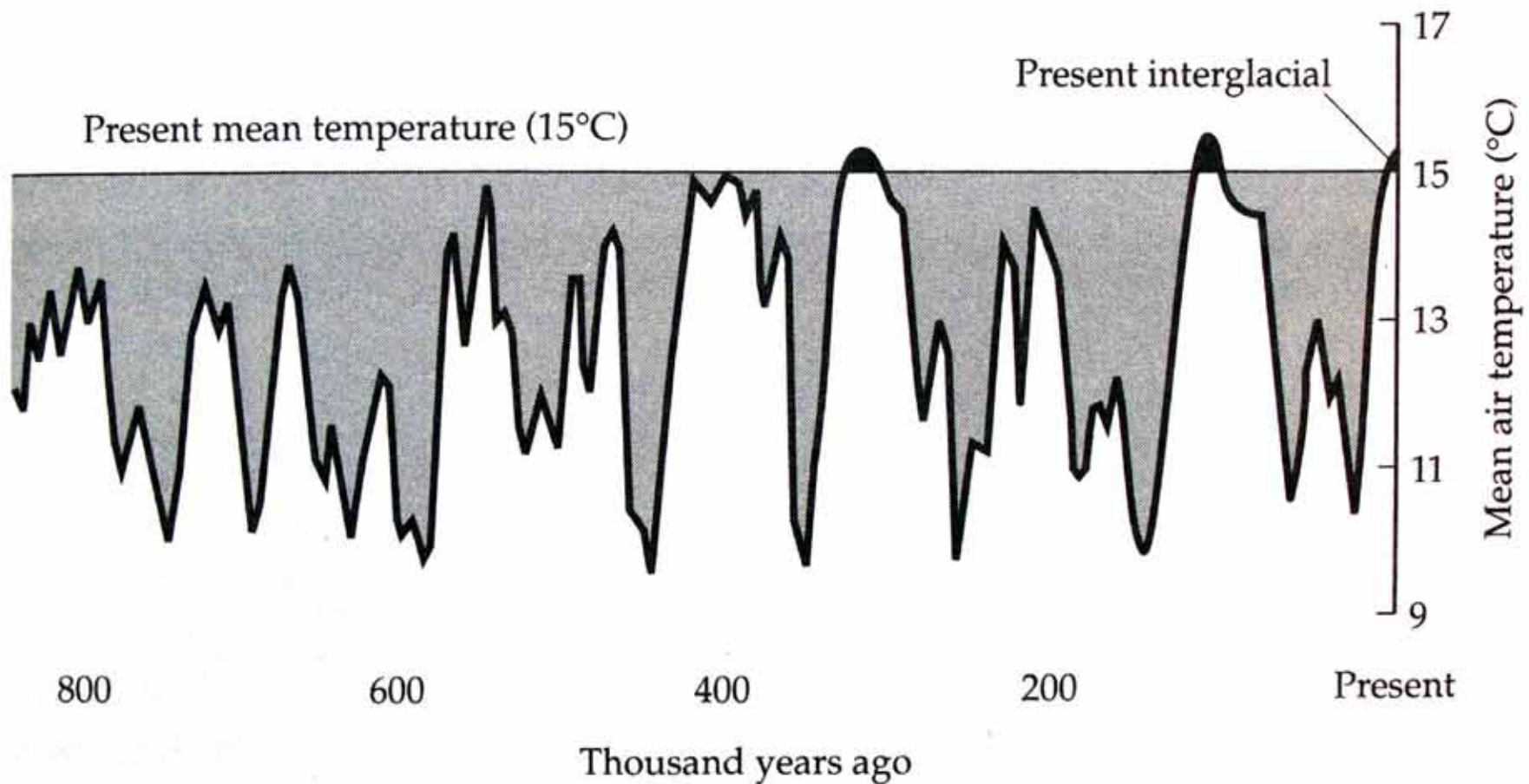
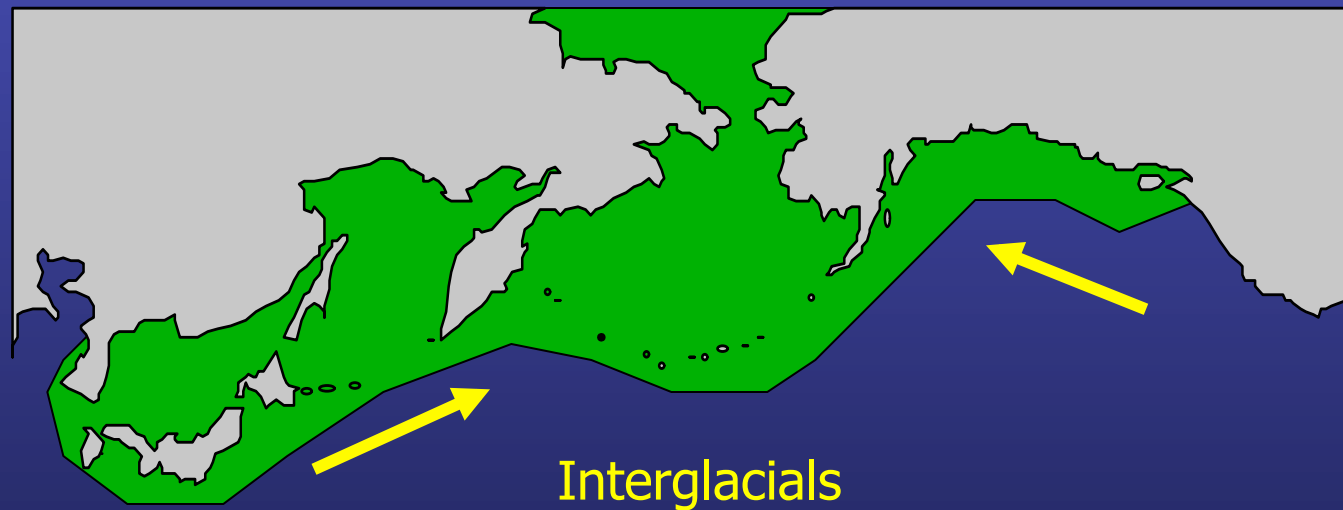
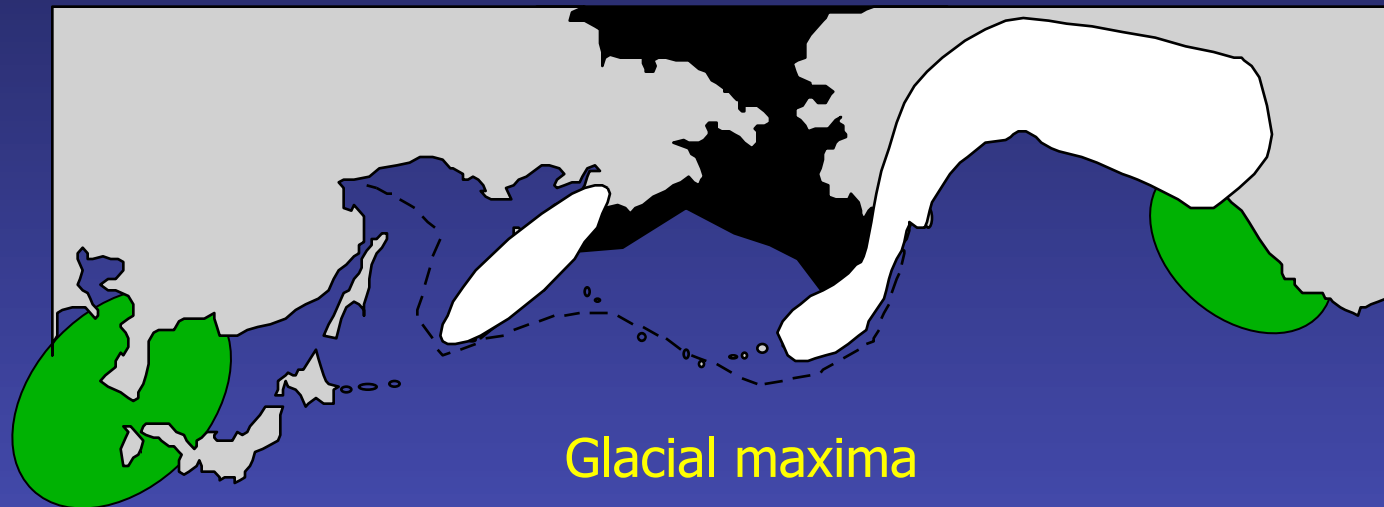
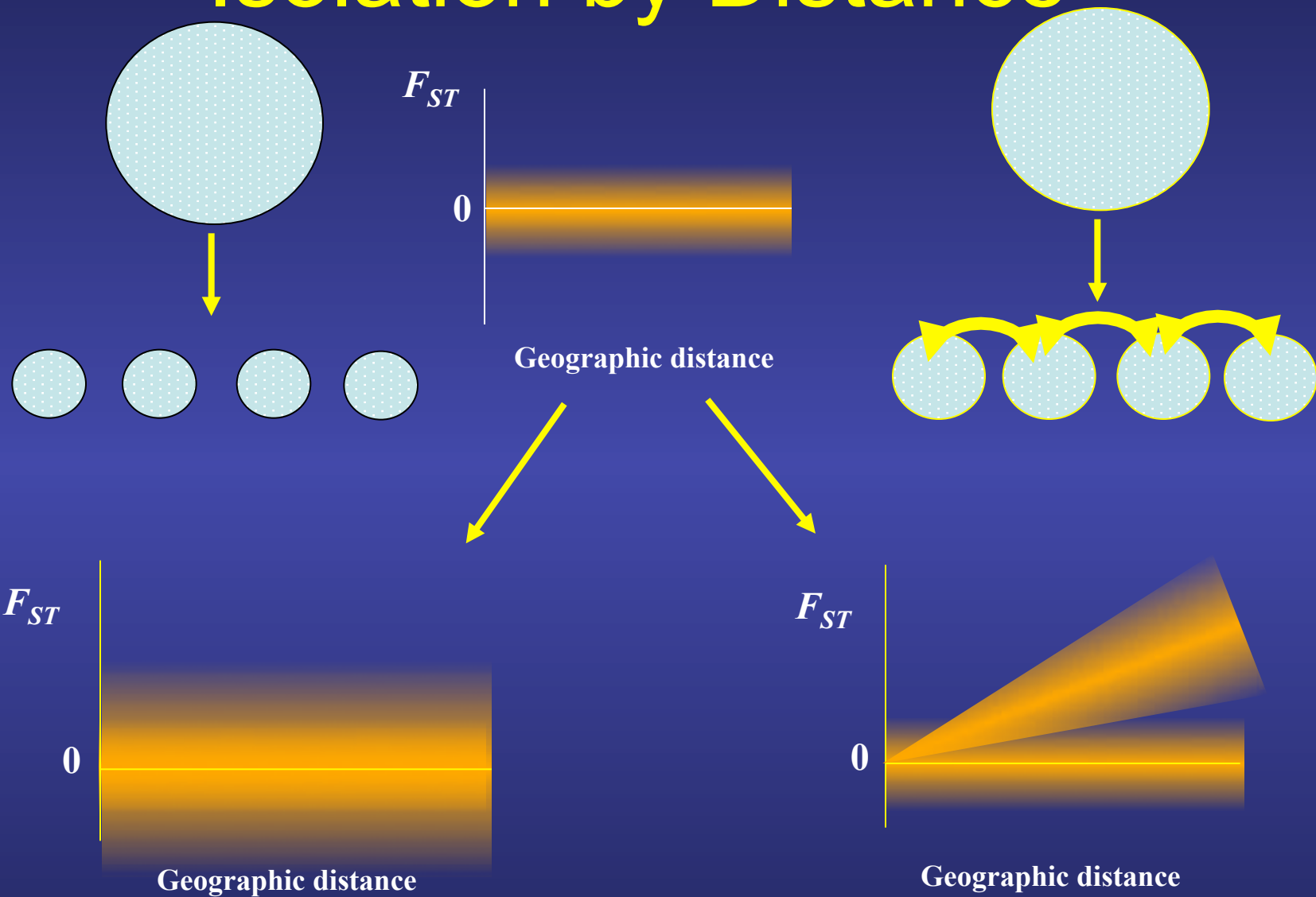


FIGURE 5 Temperature of the Earth for the last 850,000 years as inferred from ice volume derived by oxygen isotope measurements from ice cores.

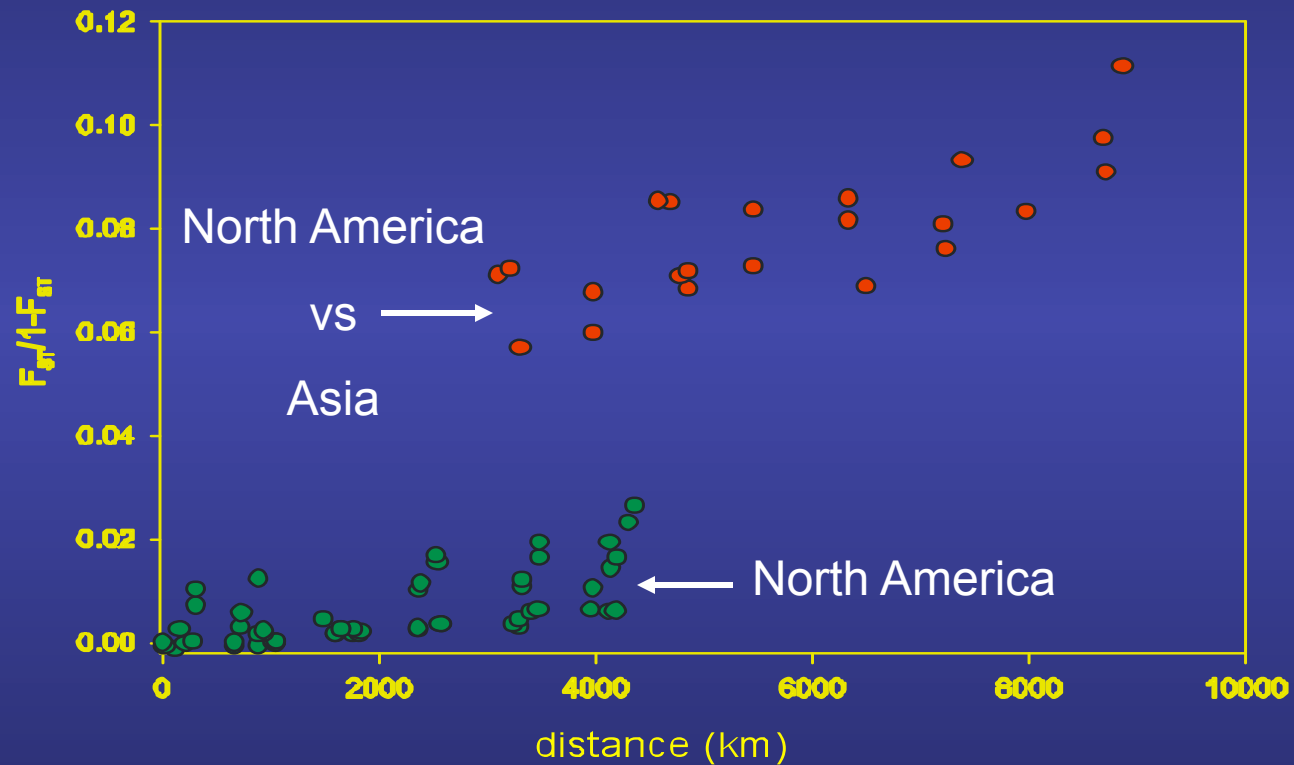
Refuge-hybrid zone model



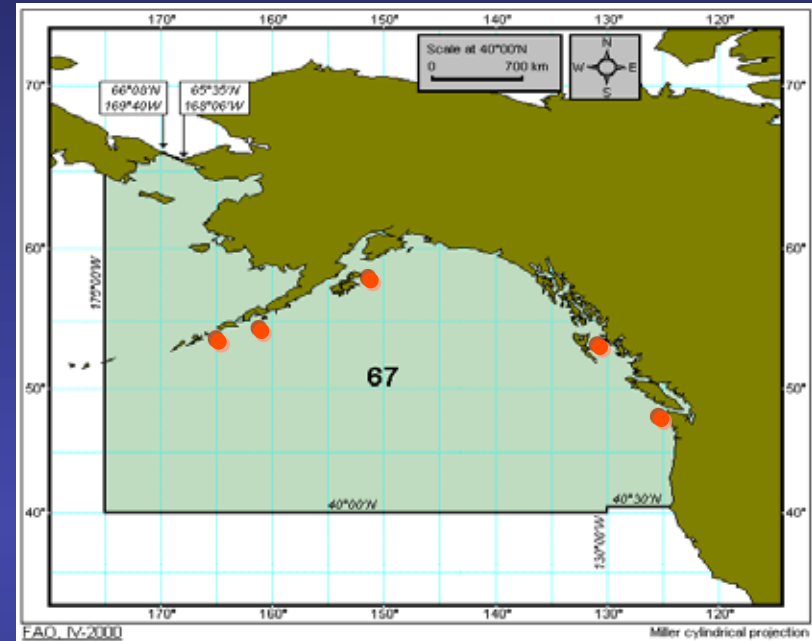
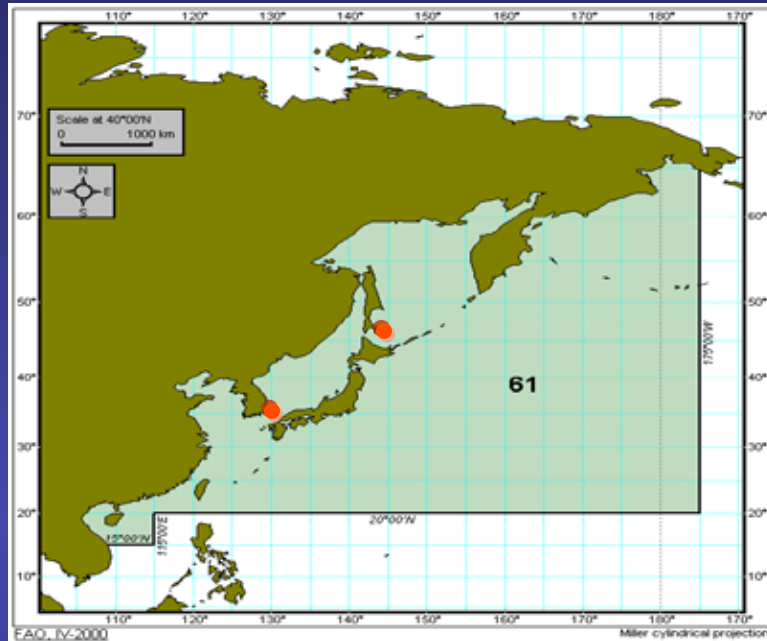
Isolation by Distance



Isolation by distance – with a twist!

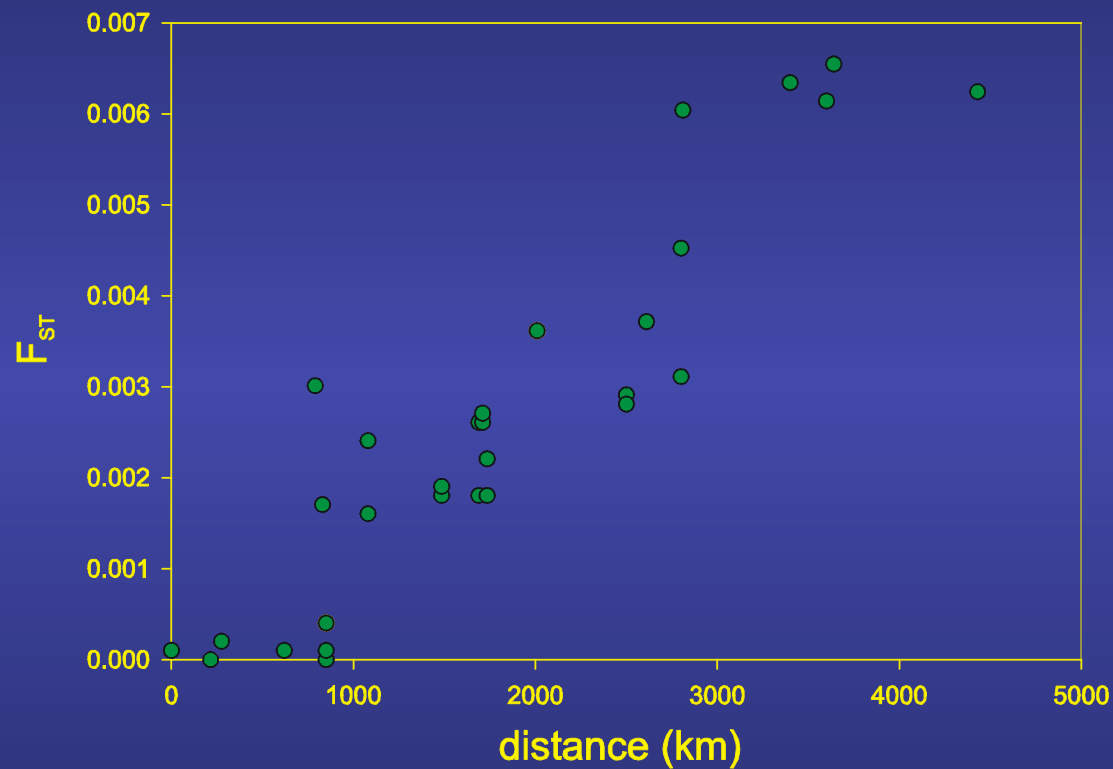


Macro-scale fishery issues



- NW Pacific fisheries and management
- Chinese exports - potential forensic use for IUU fishing/ food fraud?
- Assignment tests- Asian samples – 100% correct assignment to Asia, correct to KO or JPN ~ 97% . North America – 99.3% correct assignment

Isolation by distance – N. America



Cunningham et al. 2009

- 17 microsatellite loci
- 1000 samples (9 locations)

Near Islands

Kiska Is.

S. Amchitka Is.

Pribilof Is.

S. Tanaga Is.

Great Siskin Is.

S. Atka Is.

N. Amliia Is.

Unimak Pass

Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image IBCAO

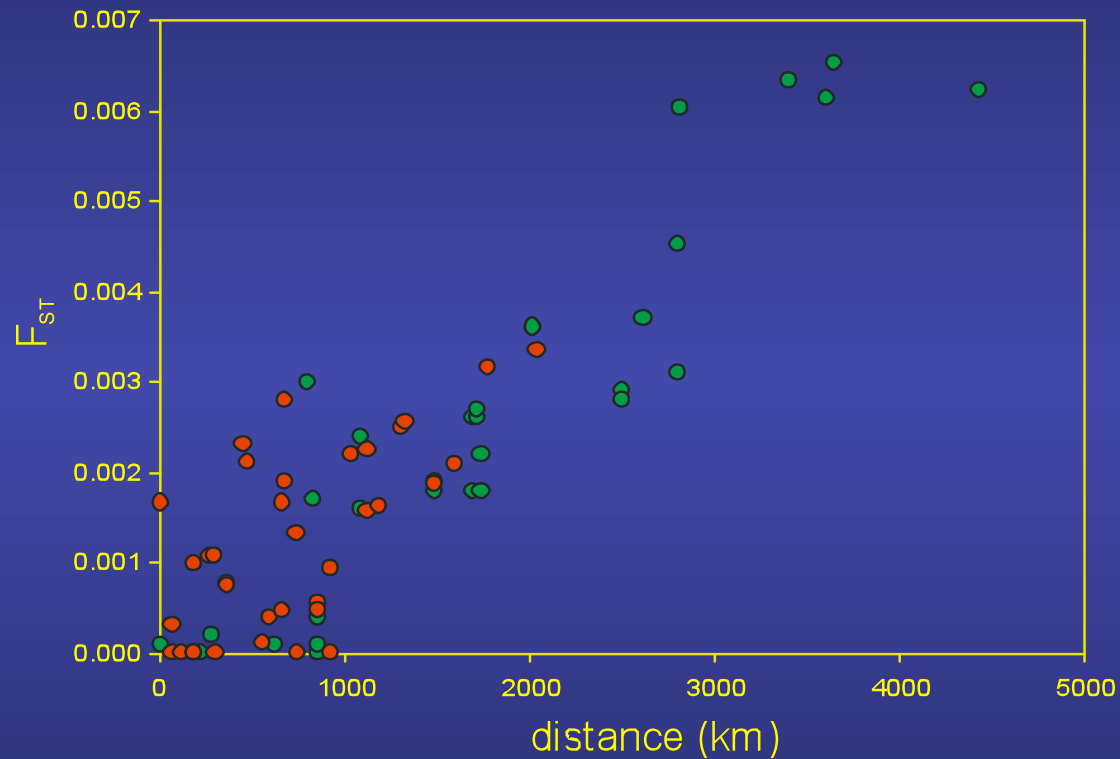
Image © 2011 TerraMetrics

Data © 2011 MIRC/JHA

60°26'21.49" N 169°39'22.41" W elev -136 ft

Spies, unpublished

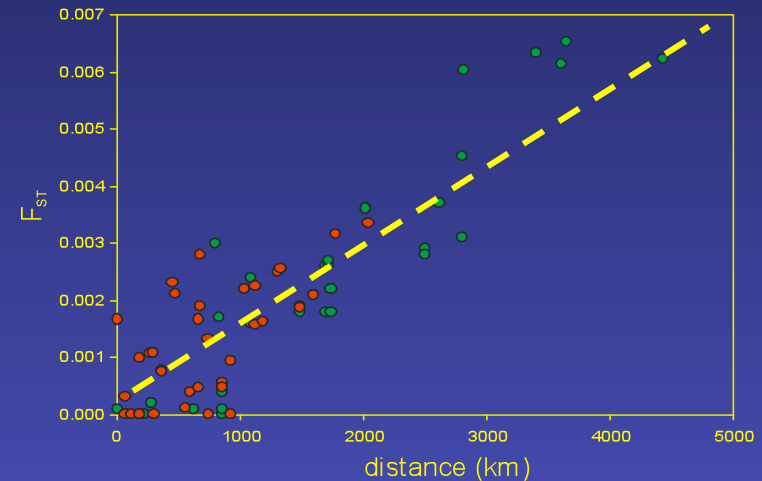
Isolation by distance – N. America



Estimated dispersal distances

- Assumptions

- Exponential dispersal curve
- Genetic equilibrium
- All locations have same dispersal
- Depends on population density

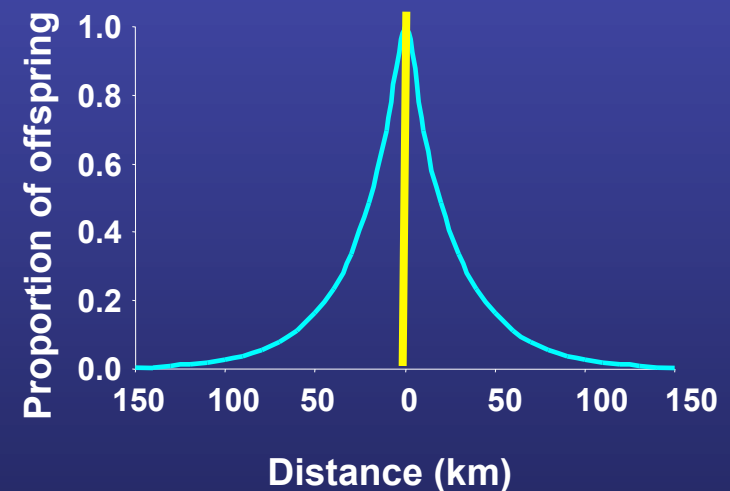


- Estimated Effective density

- Stock assessment
- $N_e/N=10^{-3}$
- N_e range 10 – 10^5 individuals / km
- mean dispersal distance –

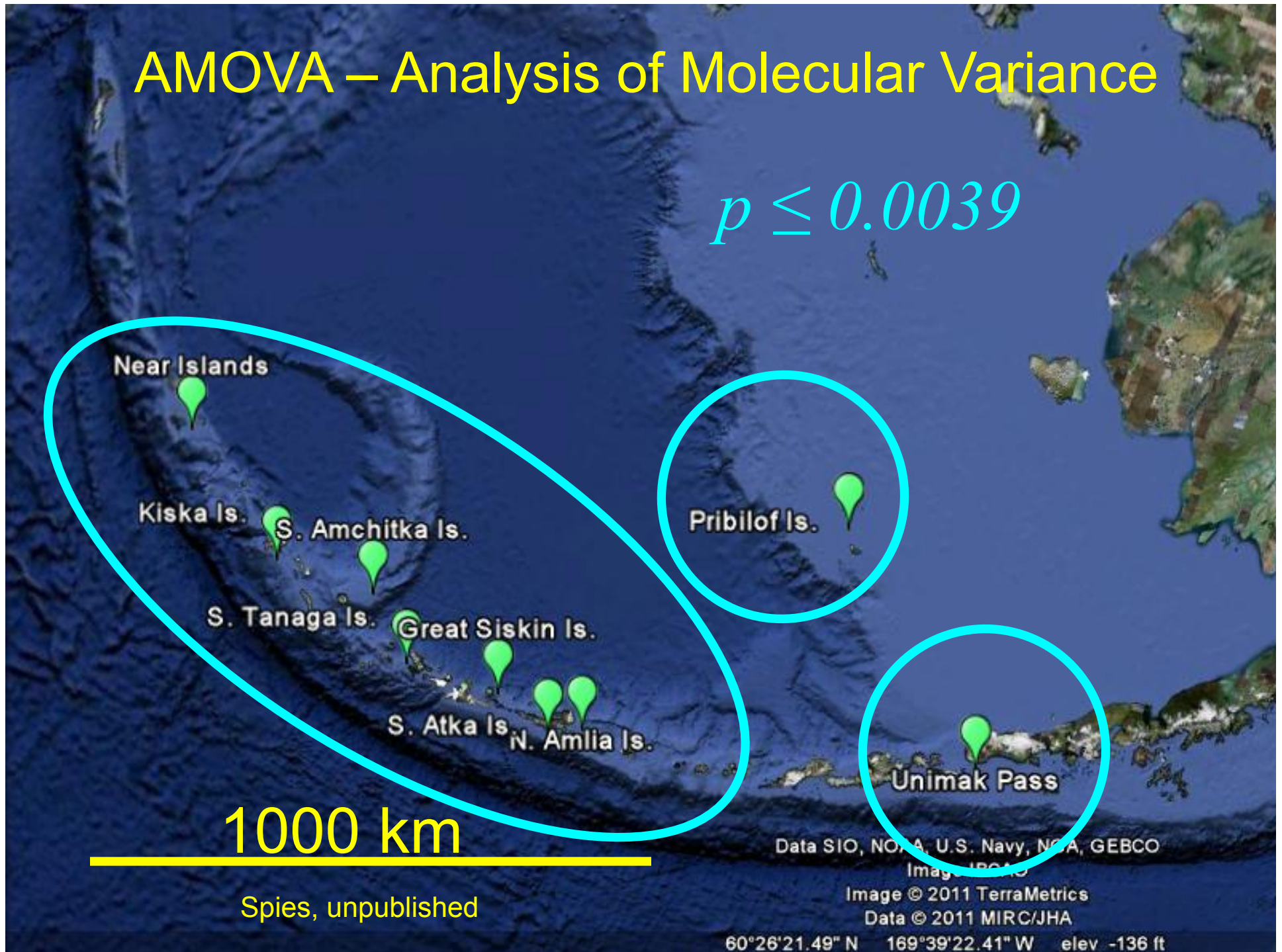
26 km/gen

Cunningham et al. 2009



AMOVA – Analysis of Molecular Variance

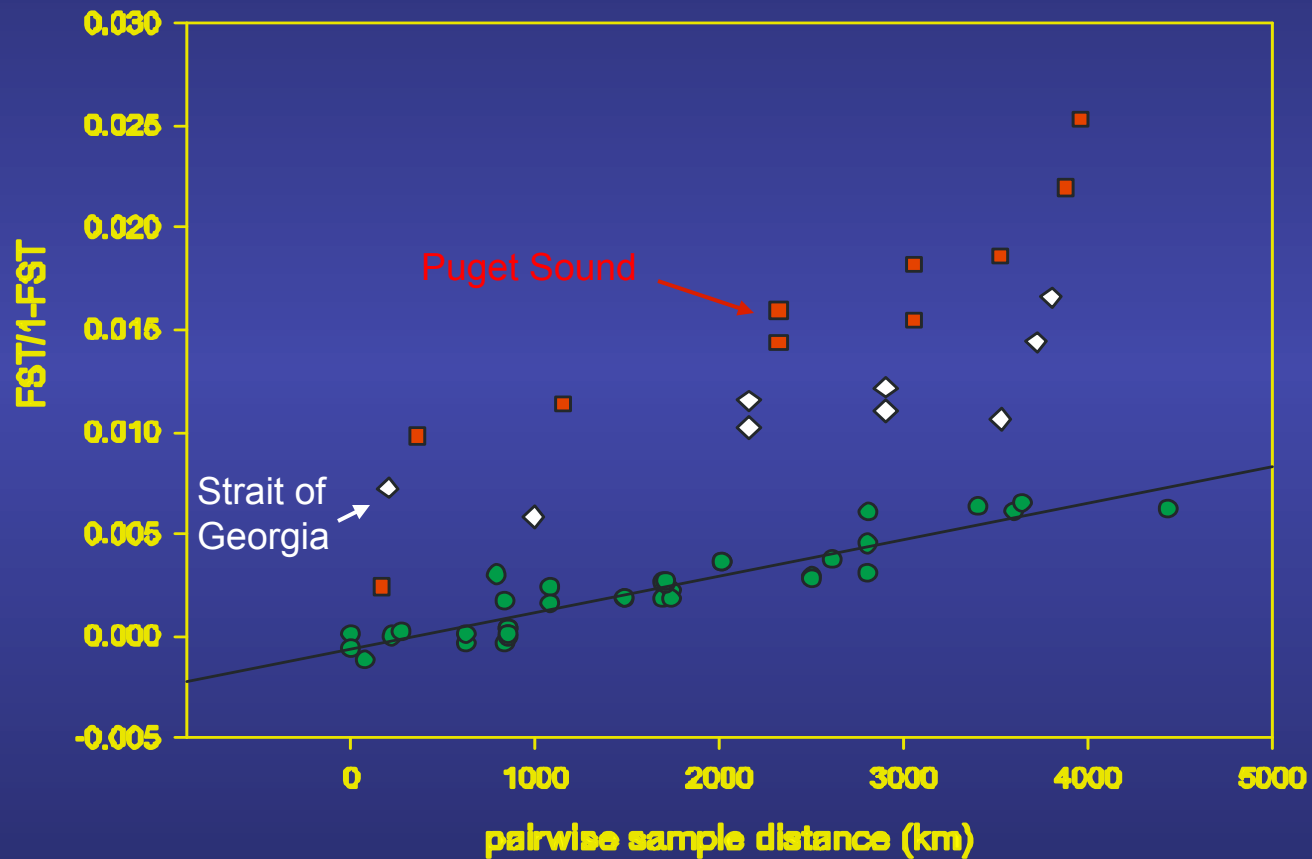
$$p \leq 0.0039$$



Incipient management actions?

- Genetic structure in Pcod comparable in magnitude to that in Acod.
- Two studies have independently demonstrated genetic subdivision within the BSAI management area
- SSC has recommended to the NPFMC to split into separate BS and AI regions

More IBD with a twist!

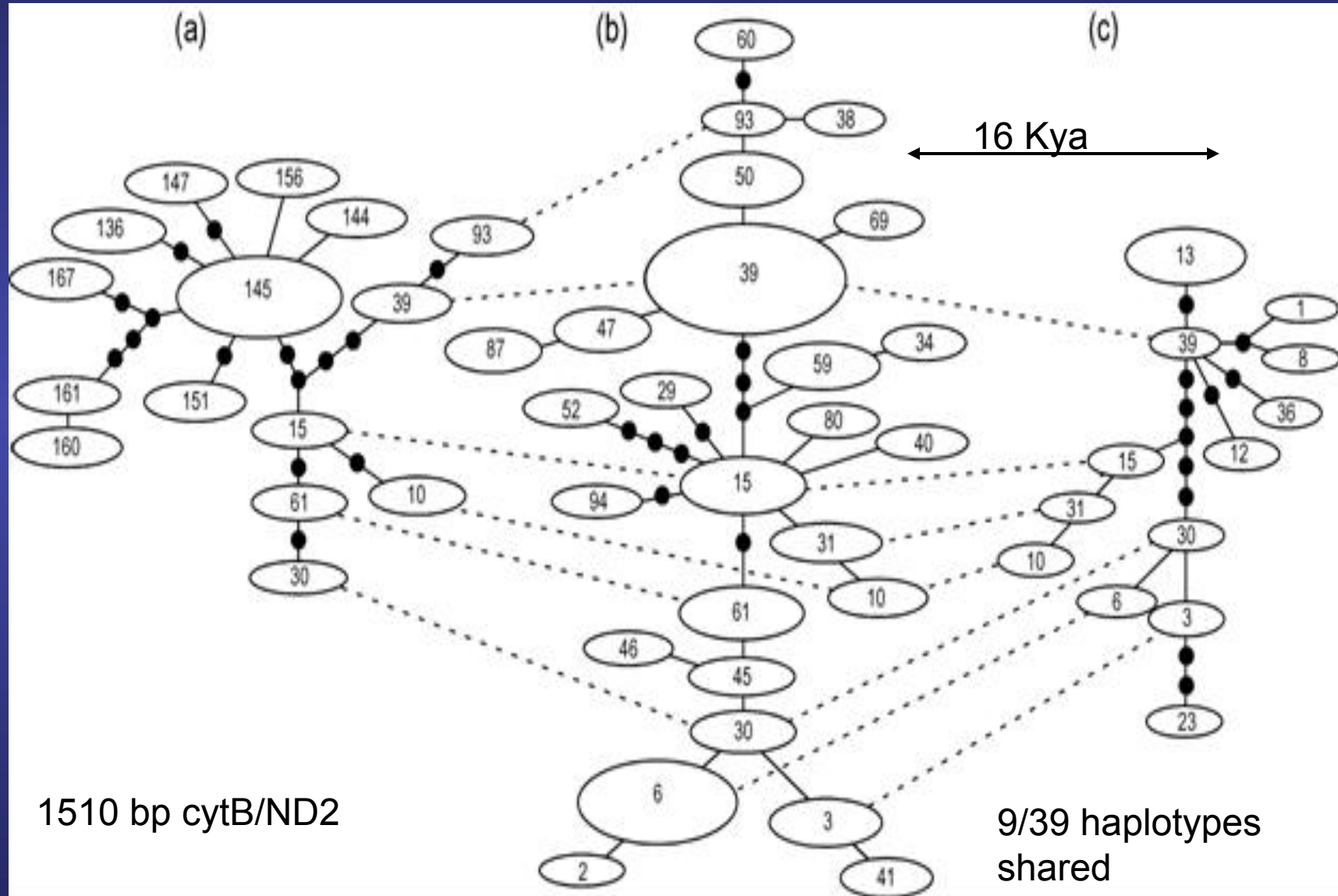


Pacific Cod – mtDNA clades

NW Pacific

NE Pacific

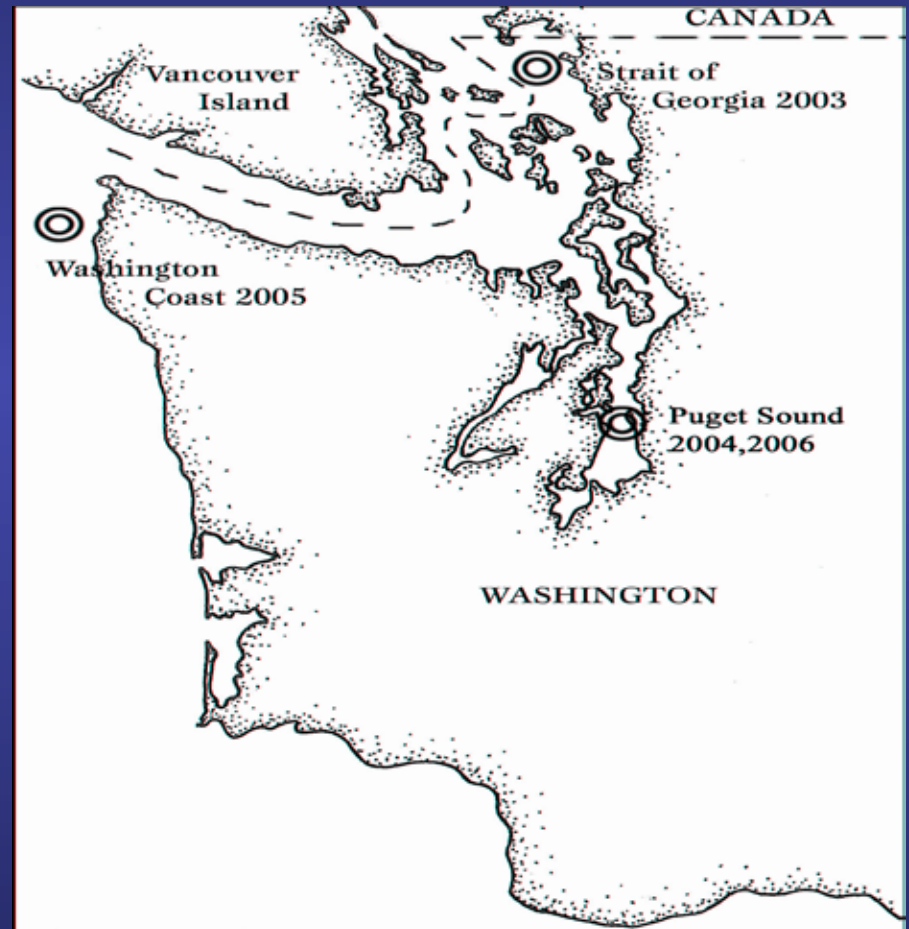
Georgia Basin



Canino et al. 2010

Evidence for localized fjord stocks

- Only one detected thus far
- Parallels in Atlantic cod
Norwegian fjords
Gilbert Bay (NW Atlantic)
- Transboundary stock issues?
- Important genetic lineage?
ESA considerations – Species of Concern





Species of Concern

NOAA National Marine Fisheries Service

Pacific Cod
Gadus macrocephalus
Salish Sea Population



Photo credit: NOAA

KEY INFORMATION

Area(s) of Concern

"Salish Sea" (i.e., Puget Sound, Strait of Georgia, Strait of Juan de Fuca)

Year Identified as "Species of Concern"
2010

Factors for Decline

- Historic overfishing
- Climate change

Conservation Designations

IUCN: Not Evaluated

American Fisheries Society: Vulnerable

Washington State: Species of Concern
and Priority Species

Current Status:

New genetic information indicates that cod in the Salish Sea represent a unique lineage and are genetically different from coastal Pacific cod (Cunningham *et al.* 2009, Canino *et al.* 2010). This information, in concert with the unique environment of the inland waters of the Salish Sea, suggests there is a separate population of Pacific cod inhabiting the Salish Sea the Strait of Juan de Fuca, Strait of Georgia and Puget Sound.

Small population size due to past overfishing is the primary threat to Salish Sea Pacific cod. Pacific cod were once abundant and an important component of the sport and commercial fisheries in the Salish Sea (Pálsson 1990). Participation in this fishery increased in the 1970s and peak harvests occurred in the late 1970s and early 1980s. Declining recreational and commercial catches led the Washington Department of Fish and Wildlife to enact fishery management changes in the early 1990s. Although commercial and recreational harvest have been greatly reduced in the

U.S. portion of the Salish Sea, cod abundance has not recovered to historic levels giving cause for concern about the species status. In the Canadian portion of the Salish Sea, recreational fishing regulations allow a year-round harvest of 8 cod daily with no size limit. There is no approved commercial fishery for Pacific cod in the Canadian portion of the Salish Sea.

Additional threats to the Salish Sea population of cod include climate change and predation (Gustafson *et al.* 2000, Beamish 2008). This population is near the southern limit of the species' range and is likely to be adversely affected by a warming climate. Other potential threats include bycatch in non-targeted fisheries (e.g., the lingcod fishery) and loss of near shore nursery habitats such as eel grass (West 1997). More research is needed to determine what factors may be limiting this population's ability to recover.

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- University of South Korea
 - Qtae Jao



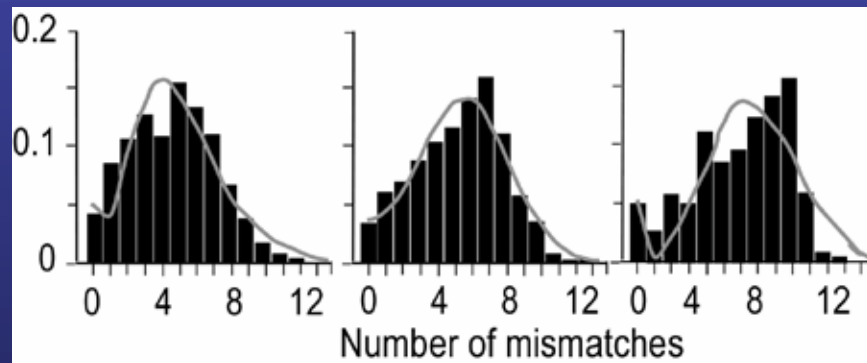
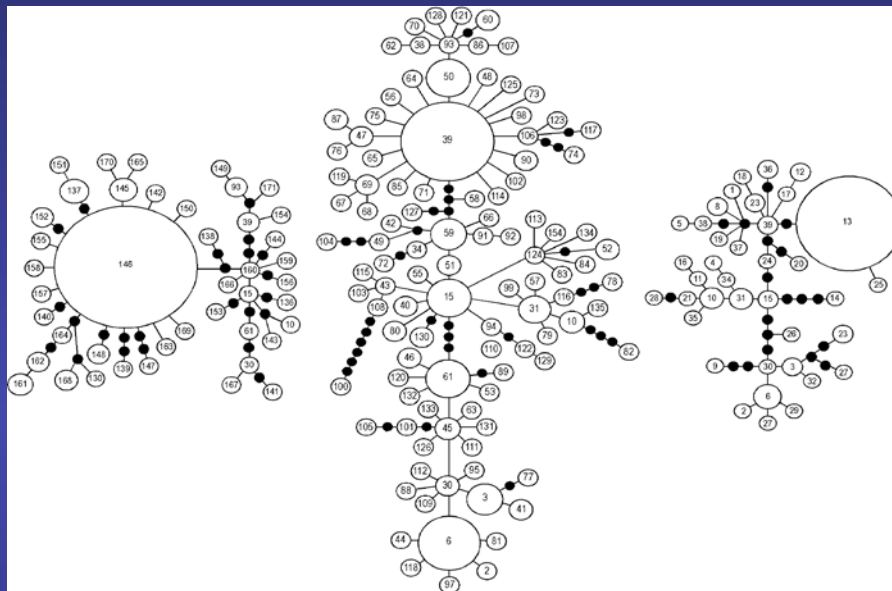
Photo courtesy Sandi Neidetcher

Pacific cod pollock

NW Pac

NE Pac

Georgia
Basin



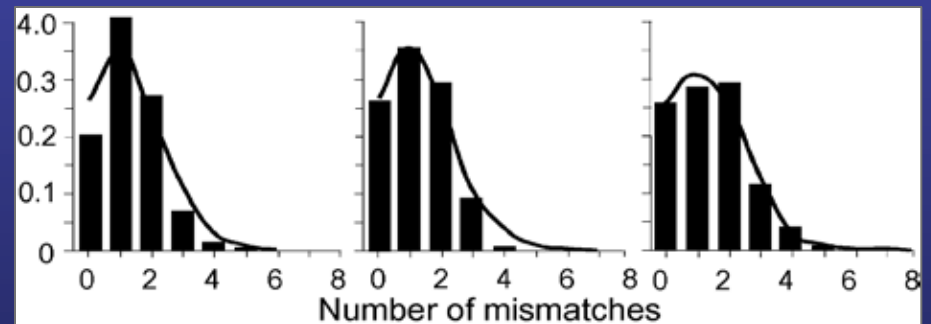
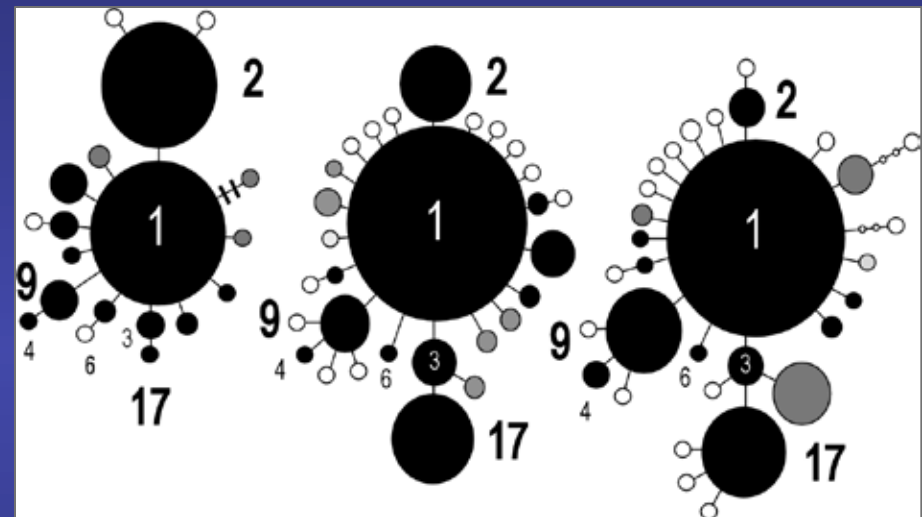
Canino et al. 2010

walleye

NW Pac

Bering Sea-Aleutians

NE Pac



Grant et al. 2010